

CALIFORNIA DIVISION OF MINES AND GEOLOGY
Fault Evaluation Report 205
Imperial, Brawley, and Rico Faults in
Imperial County, California
by
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The purpose of this report is to evaluate the 1974 Special Studies Zones (SSZ) Maps of the El Centro, Calexico, and Bonds Corner quadrangles (CDMG, 1974) for possible revision. The locations of these maps are shown on Figure 1. Revisions of these maps were recommended by Hart (1979b) as soon as the U.S. Geological Survey completed their studies of the extensive fault rupture associated with the October 15, 1979 earthquake. The USGS Professional Paper 1254 is now available and contains a detailed map and descriptions of fault rupture on the Imperial, Brawley, and Rico faults by R.V. Sharp and others (1982). The 1979 fault ruptures mapped by them generally do not coincide with the fault traces shown on the 1974 El Centro and Calexico SSZ maps and in the El Centro quadrangle rupture extends well beyond the SSZ (Figures 2 and 3). In addition, the 1940 fault ruptures shown on the Bonds Corner SSZ map are somewhat mislocated (Figure 3), based on the work of Sharp (1977b).

The Brawley, Alamo, and Holtville West SSZ maps were revised by CDMG in 1980 (Figures 1 and 2) to portray where extensive fault rupture occurred in 1979. These revised maps were largely based on preliminary mapping of fault rupture following the 1979 earthquake (Hart, 1979b) and on recent mapping by Sharp (1976, 1977a, 1977b). These maps also should be considered for revision because Sharp and others (1982) identify a number of fault traces not previously mapped, several of which extend beyond the SSZ's (Figure 2).

REVIEW OF AVAILABLE DATA

References reviewed here will be limited to the references cited on the 1974 and 1980 SSZ Maps being evaluated (Figure 1, 2 and 3) and on subsequent pertinent references. The reader is referred to FER-78 (Smith, 1978), FER-83 (Hart, 1979a) and Supplement No. 2 to these FER's (Hart, 1979b) for early references, rationale, and background data for previous zoning.

Allen and others (1972) plotted the traces of the Imperial fault based primarily on aerial photographs taken shortly after the 1940 El Centro earthquake and on unpublished notes of J.P. Buwalda. [The 1940 earthquake of M=7.1 had surface rupture of more than 60 km and maximum displacements of 6m right-lateral and 1.3m vertical (Bonilla, 1970, p. 51)]. Allen and others also monitored and mapped triggered slip after the 1968 Borrego Mtn.

earthquake. A 1:62,500-scale enlargement of their small-scale map (their Figure 54) was used as the sole source of Imperial fault data shown on the 1974 SSZ Maps of the El Centro, Calexico, and Bonds Corner quadrangles (Fig. 2 and 3). Their work was used only sparingly on the Revised 1980 SSZ maps of the Brawley and Holtville West quadrangles.

The work of Allen and others (1972) also was used to document the locations of surface rupture in 1940, 1968, and 1971. According to R.V. Sharp (personal communication, 1988), Allen and others mislocated the traces of the Imperial fault in some places, and more accurate later work should be used to revise the existing SSZ's.

Hart (1979b) was the principal source for traces of the Imperial, Brawley, and Rico faults that ruptured October 15, 1979. The traces were based on limited field mapping of DMG geologists and on the detailed interpretation of large-scale aerial photographs taken on October 16, 1979. The nature of faulting was described in some detail by Hart (1979b), and is not repeated here. Although the work was somewhat preliminary, it was immediately available for use on the Brawley, Alamo, and Holtville West SSZ maps, which previously had been issued as Preliminary Revised SSZ Maps on July 1, 1979. The preliminary maps had been largely based on the work of Sharp (1976, 1977a and 1977b), according to Hart (1979a) and Smith (1978). The three maps were again revised after the October earthquake, using the work of Hart (1979b) and Sharp (1976, 1977a, 1977b), and subsequently were issued as Revised Official SSZ Maps on January 1, 1980. The annotated fault-rupture maps of Hart (1979b) were open-filed without the text in early 1981. Because later mapping by the USGS (Sharp and others, 1982) is more comprehensive and presumably is more accurate than Hart, future zoning should be based largely on that USGS work. However, Hart (1979b and 1981) shows a few traces not shown by Sharp and others.

U.S. Geological Survey Professional Paper 1254 is a comprehensive documentation of information obtained after the October 15, 1979 Imperial Valley earthquake. It contains several papers on fault rupture, the most important being the one by Sharp and 11 others (1982). Their traces are shown in red-orange on Figures 2 and 3. The reader is referred to their paper for a detailed discussion and descriptions of faulting along the Imperial, Brawley, and Rico faults in 1979. A brief summary of their findings is provided as follows:

Imperial fault. Rupture occurred along 30 km of this fault, which coincided with the northern half of the 1940 fault rupture. The maximum right-slip displacement after the 1979 earthquake was 78 cm, of which 29 cm was afterslip. Vertical displacements were dominant to the north, amounting to as much as 41 cm of slip (down to the east). The fault

was mainly a single strand where strike-slip displacement occurred, but developed multiple branches to the north where it borders the Mesquite basin on the west. In one place the zone of multiple ruptures was 1.5 km wide.

Brawley fault. This fault, which borders the Mesquite basin on the east, ruptured discontinuously over a length of 13 km. Maximum displacements were 15 cm vertical (down-to-the west) and 7 cm right-slip, with only minor afterslip. Fault rupture also occurred in 1975 in association with an earthquake swarm.

Rico fault. This newly discovered minor fault developed several kilometers east of the other faulting. It had a maximum of 20 cm of down-to-the-west displacement.

The mapping of Sharp and others (1982) appears to be meticulous and would be the principal source of traces for any revision of the SSZ maps of this study. [According to R.V. Sharp (p.c., 1988), fault traces were initially plotted on air photos and then transferred to base maps. Because of problems with the base maps, the 1979 traces could be mislocated as much as 50 to 100 feet.] They show the 1979 ruptures to lie outside the SSZ's on the Brawley, Alamo, El Centro, and Holtville West quadrangles (Figure 2). Their traces lie as much as 200 feet (60m) east of the trace of Allen and others (1972) shown on the Calexico SSZ map (Figure 3). The 1979 ruptures of Sharp and others do not extend southeast of the South Alamo Canal on the Calexico SSZ map. For the most part, the 1979 fault traces closely follow the traces mapped by Hart (1979b and 1981) and Sharp (1976, 1977a, and 1977b), but significant differences exist between Sharp and others (1982) and Allen and others (1972).

Sharp (1977a) mapped the Holocene traces of the Brawley fault, as well as the discontinuous minor fractures associated with the earthquake swarm of early 1975. In his report, he documents the coincidence between historic rupture and pre-existing Holocene scarps and other features. The historic ruptures are discussed in additional detail by Sharp (1976), who states that rupture occurred discontinuously over a length of 10.4 km along this newly discovered fault. Maximum vertical offset along fractures was 15 mm, with less right-lateral offset. However, distributive displacement occurred over a zone 60 m or more wide and vertical displacement is assumed to exceed 20 cm. These references were cited, along with Hart (1979b), as sources of fault data used to prepare Special Studies zones maps for the Brawley fault in the Alamo and Holtville West quadrangles (figure 2). The 1975 traces of Sharp are largely coincidental with the 1979 traces of Hart (1979b), all of which are shown undifferentiated on Figure 2. The 1979 traces of Sharp and others (1982) differ only slightly in location from the zoned traces but are more extensive.

Sharp (1977b) mapped Holocene traces of the entire Imperial fault based on field and air photo interpretations. His traces closely follow the 1979 traces of Hart (1979b) and Sharp and others (1982) and, therefore, are not plotted separately on figures 2 and 3 (see exception below). However, his work was used for continuity and is cited on the 1980 revised SSZ maps of the Brawley and Holtville West quadrangles. A few traces of Sharp (1977b) are shown in purple on the Bonds Corner and Calexico quadrangles where they do not coincide with or extend beyond the 1979 ruptures.

Brune and Allen (1967) documented minor rupture on the Imperial fault in association with a small, 1966 earthquake. Although they do not map the ruptures in detail, they were cited as a source of data on the 1980 SSZ map of the Holtville West quadrangle.

The only other reference cited on the SSZ Maps in the study was by Dibblee (1954), who mapped an inferred southeastern trace of the Superstition Hills fault in the western part of the Brawley and El Centro quadrangles (Figure 1). The basis for this fault segment is uncertain, but presumably is the right bend in New River. According to Treiman (1989), this fault segment did not rupture following the November 1, 1987 earthquake, there is no surface evidence for its existence, and the fault should be deleted from the Revised SSZ maps of the Brawley quadrangle and relocated on the El Centro quadrangle. Fault traces identified by Sharp and others (1989) in the El Centro quadrangle lie on the projection of surface rupture which occurred in 1987 in the adjacent Seeley quadrangle and are discussed by Treiman (1989).

SEISMICITY

The Imperial and Brawley faults are as seismically active as any fault in California in terms of both macroseismicity and microseismicity. The largest earthquakes caused historically by the Imperial fault were $M=7.1$ in 1940 and $M=6.6$ in 1979 (Figure 4; Johnson and Hill, 1982). Other earthquakes of $M=6.3$ and $M=6.0$ occurred in 1915 and 1906, with lesser events in 1917 and 1927.

The Brawley fault does not seem to produce large earthquakes by itself, but ruptures coseismically with the Imperial fault during larger earthquakes. Numerous small earthquakes also occur along the Brawley fault and its northern extension (Figure 4). No surface faults are known north of Brawley along this so-called Brawley seismic zone.

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD OBSERVATIONS

Although no field and airphoto studies were made for this fault evaluation report, detailed studies were made previously by this writer (Hart, 1979b and 1981). Detailed studies also were

made prior to the October 15, 1979 earthquake by Sharp (1976, 1977a, and 1977b) and after the earthquake by Sharp and others (1982). In view of these detailed studies, it seems unnecessary to duplicate comprehensive work that was done previously.

CONCLUSIONS AND DISCUSSION

The Imperial fault was unknown prior to the Imperial Valley earthquake of 1940. At that time, surface rupture delineated the Imperial fault over its entire length of 60 km or more (Allen and others, 1972) with maximum displacements of 6m right-lateral and 1.3 m vertical (Bonilla, 1970). Major displacements occurred again along the northern half of the Imperial fault in 1979, with maximum slip of 78 cm right-lateral and 41 cm vertical. Lesser rupture events also occurred in 1966, 1968, 1971, 1975, and 1987-- mostly slip triggered by earthquakes on other faults. The locations and magnitudes of rupture are based on interpretations of 1940 aerial photographs and notes of J.P. Buwalda by Allen and others (1972) and Sharp (1977b). Following the El Centro earthquake of 1979, fault rupture along 30 km of the fault with up to 78 cm of coseismic slip and afterslip was mapped by DMG (Hart, 1979b, 1981) and Sharp and others (1982). These surface ruptures (Figure 2 and 3) largely coincided with the previous mapped Holocene faults of Sharp (1977b).

The Brawley fault also was unrecognized as a surface feature until January-February 1975 when minor surface rupture occurred discontinuously along a 10.4-km segment of the fault in conjunction with an earthquake swarm. Similar displacement--7mm right-lateral, 24mm vertical slip--occurred again in October 1979, but over a somewhat greater length and on additional branches. Most of the fault strands were identified as Holocene scarps and photolineaments in alluvium by Sharp (1977a) based on the interpretation of air photos (Figure 2).

The Rico fault is a newly recognized scarp that formed in association with the October 15, 1979 earthquake (Figure 2). Vertical displacement (down to the west) across a 20m-wide zone was 20cm and maximum rupture length was about one kilometer. Only indirect evidence is available that this minor fault existed prior to the earthquake and no evidence is available to indicate that it extends beyond the rupture zone (Sharp and others, 1982, p. 142).

It is readily apparent that the Imperial, Brawley, and Rico faults meet the zoning criteria of "sufficiently active and well defined" (Hart, 1988). The main concern is that the previous Special Studies Zones maps of 1974 and 1980 (CDMG 1974, 1980) are inadequate. On four of the SSZ maps (Brawley, Alamorio, El Centro, and Holtville West) fault ruptures from the 1979 earthquakes extend beyond the delineated zones (Figure 2). On the Calexico and Bonds Corner SSZ maps, the 1979 rupture-traces

and the Holocene/1940 fault traces are mislocated as much as 200 feet and 300 feet, respectively (Figure 3).

RECOMMENDATIONS

It is recommended that the existing Special Studies Zones Maps of the following quadrangles be revised: Brawley (1980), Alamorio (1980), El Centro (1974) Holtville West (1980), Calexico (1974), and Bonds Corner (1974). All of these maps contain faults that have been historically active but are not as accurately shown as they should be. In fact, the first four maps named above have faults that extend outside of the existing SSZ's. The other maps have historically active traces that are mislocated as much as 300 feet. In addition, the SSZ's on the 1974 maps are wider than the later maps, as a result of a change in zoning policy.

Figures 5 and 6 identify the faults to be plotted on the revised maps and the suggested zone revisions. They also identify the references to be cited on each SSZ map. Sharp and others (1982) is the principal reference for all maps except Bonds Corner. Sharp (1977b) should be used for the latter. Accessory traces and information should be Sharp (1976, 1977a, 1977b) and Hart (1981). Also, this FER (Hart, 1989) should be cited on all maps for the rationale used in revising these maps.

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